Next-Generation Sensors for Neuromagnetism I

Organizers: Lauri Parkkonen and Justin Schneiderman

Room:# 105

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Neuromagnetic Measurements beyond Low-Tc SQUIDs: Session 1
MEG has provided significant insights into the workings of the human brain and improved our ability to treat it in disease. MEG has also been the main technology driver in the field of biomagnetism; to date, the low-Tc SQUID has remained the sensor of choice for MEG. However, the emerging new generation of magnetic sensor technologies enables finer-grained sampling of the neuromagnetic field that the head surface for on-scalp MEG and within the neural tissue for invasive magnetoneurography. By moving beyond the limitations of low-Tc SQUIDs, these new approaches hold promise for major advancements over the state of the art in neuromagnetic recordings: the substantial increase in spatial resolution and signal-to-noise ratio as well as access to neuron-scale magnetic signals may drastically change our field. This symposium will not only provide an up-to-date picture of several sensor technologies that may rival low-Tc SQUIDs in neuromagnetism but it will also illustrate the value of these novel technologies for MEG. In addition, the symposium covers the challenges in moving from demonstrations with single sensors to practical systems.

Speakers:

- **Matti S. Hämäläinen** (Boston Children's Hospital, USA)
  "Hopes and dreams for on-scalp MEG"

  Thanks to their high sensitivity, low noise, and reliable operation, low-Tc SQUIDs are employed in all present whole-head MEG systems. However, these sensors need liquid helium as a refrigerant and thus the maintenance costs are relatively high and the distance between the sensors and the head in room temperature is typically of the order of 20 mm. The newest low-Tc SQUID MEG systems, e.g., our BabyMEG device, employ closed-circuit refrigeration eliminating the need of regular helium refills. While the sensor to room temperature distance can be thus reduced to about 6 mm, the dewar is still of fixed size. If high-sensitivity sensors operating without or with simple cooling could be produced, one could imagine an MEG system with an individualized helmet hosting an array of individual MEG sensors or "magnetrodes" immediately on the scalp of the subject. Provided that the noise level of the sensors is low enough, such a system would provide clear benefits in terms of spatial resolution and ability to detect sources which are temporally coherent over only small distances on the cortex. This talk will discuss the design constraints and challenges in the operation of such a fictional system.

- **Justin F. Schneiderman** (Univ. of Gothenburg and the Inst. of Neuroscience and Physiology, Sweden)
  "High-Tc SQUIDs for on-scalp MEG"

  High-Tc SQUIDs are a promising technology for on-scalp MEG (OS-MEG) for a number of reasons. First and foremost, they can be used to sample the neuromagnetic field at a distance of less than one mm from the head surface. Micro-cryocooling systems are furthermore reaching a level of maturity that enables development of a flexible OS-MEG sensor array that would fit arbitrary head sizes and shapes while eliminating the need for liquid cryogens. The translation of existing MEG sensor control and readout hardware and software to a high-Tc SQUID-based OS-MEG system is also straightforward because the operating principles of our sensors are the same as their low-Tc counterparts. Furthermore, the noise levels of high-Tc SQUIDs are sufficient for OS-MEG, especially in the low-frequency range (< 10 Hz). In this talk, I will present our sensor technologies, results from benchmarking experiments on somatosensory and auditory evoked fields, and progress towards a whole-head high-Tc SQUID-based OS-MEG system.

- **Jürgen Dammers** (Forschungszentrum Jülich, Germany)
  "High-Tc SQUID based MEG experiments and data analysis"

  The technology of high-Tc SQUID has significantly been improved in recent years. Now the magnetic field resolution of high-Tc SQUIDs is comparable to that of standard low-Tc SQUIDs, which are typically employed in modern commercial whole-head MEG systems. In particular, a higher sensitivity in the low frequency range (<10Hz) has been achieved and demonstrated for high-Tc SQUIDs to now allow for source analysis. Results from MEG recordings using high-Tc SQUID will be presented and compared to those obtained from a standard low-Tc SQUID -based MEG system. Resting state brain activity from visual areas as well as evoked magnetic fields from sensory, motor and auditory regions will be shown together with findings from time–frequency decompositions and source localizations. In this talk, I will demonstrate that results obtained with a high-Tc SQUID system are in good agreement with those obtained from a commercial low-Tc MEG system. More importantly, the results indicate that the sensitivity of high-Tc SQUIDs is ready for MEG analysis including source localization.

- **Svenja Knappe** (NIST, Univ. of Colorado, Boulder, USA)
  "Small-sized OPMs for an MEG prototype array"

  Optically-pumped magnetometers (OPMs) can be optimized for a variety of applications. In biomagnetism, close proximity between source and sensor is very important and should be balanced with best noise performance of the sensor. Here, we demonstrate a prototype MEG array with an OPM sensor holder inspired by stereotactic frames. The uncooled chip-scale OPMs are sufficiently small to have the sensing volume at a distance of only a few millimeters from the scalp. Operating the OPMs in a low field environment allows for the recording of the N20m in human subjects with sufficient fidelity to apply standard biomagnetic processing. Averaged responses show amplitudes in the pT-range, the well-known dipolar field structure of cortical current sources is reproduced, and the result from an estimation of the cortical current is consistent with known SQUID results. This demonstrates the potential use of OPMs for biomagnetism either complementing SQUIDs or even replacing them at least in some applications. Fortunately, the large investment in post-acquisition processing can be retained from SQUIDs.

- **Peter Schwindt** (Sandia Nat'l Laboratories, USA)
  "Towards a multi-channel magnetoencephalography system using optically pumped magnetometers"

  There have been several demonstrations of using optically-pumped magnetometers (OPMs) to measure magneto-encephalographic signals. Following these demonstrations, there are several groups developing multi-channel OPM arrays to localize magnetic sources within the brain. We are working to develop a complete MEG system including a person-sized magnetic shield and a 36-channel array of OPMs. The current goal is to use the array to localize the magnetic sources in the auditory and somatosensory cortices associated with auditory and median nerve stimulation, respectively. The 36-channel array will consist of nine 4-channel sensor modules where the channels within each sensor are spaced by 18 mm and each sensor covers a 40 mm by 40 mm area of the head. The sensitivity of the magnetometer channels inferred from gradiometric measurements is < 5 $fT/Hz^{1/2}$ over a frequency range of 5 to 100 Hz. We will present results on the performance our OPM array in the person-sized shield and preliminary studies with human subjects. Finally, we will highlight system-level issues encountered in the development our OPM-based MEG system.